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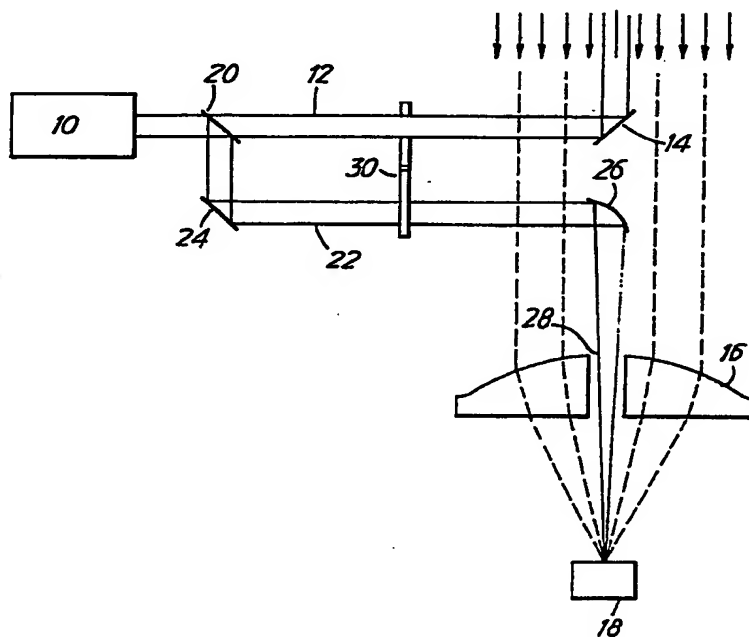


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## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

<b>(51) International Patent Classification <sup>5</sup> :</b>  <b>G01S 7/48, 17/32, G02B 3/00</b>	<b>A1</b>	<b>(11) International Publication Number:</b> <b>WO 92/05455</b>  <b>(43) International Publication Date:</b> <b>2 April 1992 (02.04.92)</b>
<b>(21) International Application Number:</b> PCT/GB91/01590 <b>(22) International Filing Date:</b> 17 September 1991 (17.09.91)  <b>(30) Priority data:</b> 9020285.4                      17 September 1990 (17.09.90) GB  <b>(71) Applicant (for all designated States except US):</b> IMATRON- IC LIMITED [GB/GB]; Kingfisher Court, Hambridge Road, Newbury, Berkshire RG14 5SJ (GB).  <b>(72) Inventor; and</b> <b>(75) Inventor/Applicant (for US only) :</b> STREET, Graham, Ste- wart, Brandon [GB/GB]; Impstone House, Pamber Road, Silchester, Reading, Berkshire RG7 2NU (GB).  <b>(74) Agent:</b> GARRATT, Peter, Douglas; Mathys & Squire, 10 Fleet Street, London EC4Y 1AY (GB).		<b>(81) Designated States:</b> AT (European patent), AU, BE (Euro- pean patent), CA, CH (European patent), DE (Euro- pean patent), DK (European patent), ES (European pa- tent), FR (European patent), GB (European patent), GR (European patent), IT (European patent), JP, LU (Euro- pean patent), NL (European patent), SE (European pa- tent), US.  <b>Published</b> <i>With international search report.            Before the expiration of the time limit for amending the            claims and to be republished in the event of the receipt of            amendments.</i>

**(54) Title:** OPTICAL APPARATUS**(57) Abstract**

Optical distance measuring apparatus has a focusing lens (16) directing light reflected from a target toward a detector (18). The lens has discrete or continuous zones each associated with a target distance. The area of the lens zones increases with an increase in associated target distance so as to compensate for a reduction in intensity according to the inverse square law.

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<sup>+</sup> Any designation of "SU" has effect in the Russian Federation. It is not yet known whether any such designation has effect in other States of the former Soviet Union.

## OPTICAL APPARATUS

This invention relates to optical apparatus and in particular to arrangements for the efficient collection of light reflected from a target at varying distances. The invention finds particular application with laser-based measuring devices utilising reflection to gauge a target distance.

The efficient collection of light transmitted in a beam and reflected back from a target, is easy to achieve if the distance to the target is known and constant. If the target distance varies, two main difficulties result.

First, one focusing lens may no longer be adequate to focus light onto the detector over the working distance range of the optical apparatus. A possible solution to this problem is to allow the user of the apparatus to estimate the target distance, to choose from a number of interchangeable lenses, and to insert the chosen lens into the apparatus. This solution allows proper focusing onto the detector but is clumsy for the user. One object of this invention is to reduce the effort required from the user without reducing the range of the apparatus.

Second, the intensity of the light focused onto the detector must normally lie within certain levels if the detector is to function correctly. With a very distant target, the intensity of reflected light is low and the detector may not respond. Conversely, if the target is extremely close, the intensity of the reflected light may be so high as to saturate the detector. Previously, this problem has been overcome by allowing the user to choose from a variety of interchangeable filters, one of which is then placed in the path of the received light. The sensitivity of the detector is selected to give the required maximum range and the filters are used to attenuate light from closer targets. A further object of this invention is to avoid the complications and inconvenience of interchangeable filters.

Accordingly, the present invention consists in optical apparatus comprising a light beam source; light detector means and convergent optical means for directing light returned from a target onto the detector means, characterised in that the convergent optical means comprises a plurality of zonal elements each having an associated target distance at which returned

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light is directed optimally onto the detector means, the light gathering capability of the respective elements varying as between the elements with an increase in associated target distance so as to compensate for the reduction in the intensity of reflected light as a function of said distance.

Preferably, the light gathering capability of the respective zonal elements increases by virtue of an increase in the associated elemental area.

Advantageously, the zonal elements comprise respective refractive surface zones.

Suitably, the refractive surface zones are disposed concentrically of the light beam axis.

In one form of the invention, the zonal elements comprise respective zones of a first refractive surface, the convergent optical means including a second refractive surface, the first and second refractive surfaces being rotationally symmetric about respective, mutually spaced axis.

The invention will now be described by way of examples with reference to the accompanying drawings in which:-

Figure 1 is a schematic diagram of laser based distance measuring apparatus incorporating the present invention;

Figure 2 is a plan view of the focusing lens shown in Figure 1;

Figure 3 is a response curve illustrating the operation of the present invention;

Figure 4 is a schematic diagram of distance measuring apparatus in a different embodiment of this invention;

Figure 5 is the plan view of a focusing lens shown in Figure 4;

Figure 6 is a graph illustrating the contour of the refractive surface shown in Figure 5; and

Figure 7 illustrates schematically a modification of the apparatus of Figure 4.

There are a wide variety of published techniques for the measurement of distance by detecting light from a modulated beam which is reflected from a distant target. A focusing lens or other convergent optical means will typically be provided to direct the reflected light onto a single optical detector. This invention is particularly concerned with the detail of the

optical convergent means and, in the following specific description, attention will be concentrated on this aspect of the apparatus. A detailed description will not be given of other aspects of the apparatus since these may be of conventional form and can be readily ascertained by the skilled man from the published literature.

Referring now to Figure 1, distance measuring apparatus comprises a collimated light beam source 10 producing a beam 12 which is directed by a mirror 14 towards a target (not shown). A lens 16 is positioned co-axially with the outgoing light beam and serves to focus light reflected from the target onto a detector 18.

A beam splitter 20 in the path of the light beam 12 directs a calibration beam 22 by mirrors 24 and 26 onto the axis of the lens 16. A central aperture 28 in the lens allows the calibration beam to pass directly to the detector 18. A chopper illustrated schematically in the form of a rotating disc 30 serves to break, alternately, the main beam and the calibration beam.

In a manner which may be entirely conventional, the amplitude of the light beam 12 is modulated and a distance measurement made by comparing the phase of the modulation in the incident and reflected beams. By performing the same phase comparison for the calibration beam 22, which of course travels over a known distance, an absolute measure of the distance to the target can be achieved.

In accordance with the present invention, the lens 16 is provided with zonal elements, each associated with a particular target distance. As shown in Figure 2, the zonal elements 32, 34 and 36 are annular and are concentric with the axis of the lens and thus with the axis of the transmitted light beam. Each zonal element has a different focal length so as to focus, optimally, light reflected from an associated target distance which is different from the target distances associated with the other zonal elements. Of course, each zonal element will focus some light onto the detector for target distances which are away from the associated distance at which focusing is optimal. Thus, for a particular target distance, there may be contributions from two or more zonal elements.

In accordance with this invention, the effective areas of the respective zonal elements are chosen so as to compensate for the decrease in the intensity of reflected light at increasing target distances. Thus, the annular zonal element 32 corresponding with the closest target distance is relatively small whilst the area of the annular zone 36 corresponding with the most distant, is relatively large. The intensity of the reflected light will vary according to the inverse square law and it will be recognised that the areas of the zonal elements can be chosen so as to produce a sensibly constant intensity of light at the detector, irrespective of variations in target distance, within of course the working range.

There is shown in Figure 3, a response curve showing the detected light intensity at varying target distances. Within the response curve, contributions can be identified from each of the zonal elements and these are depicted in dotted outline. The composite response curve has variations but these lie within the sensitivity levels of the detector, over a considerable range in target distance.

It will be understood that the compensation which is provided for the variation in intensity over differing target distances, will be designed to meet the characteristics of a particular detector system. In many cases, the compensation will be partial in that the detector system will tolerate small variations in intensity. In appropriate cases, the compensation will produce a detected intensity which is not constant but which has a desired variation with distance.

Whilst the zonal elements have been described as discrete annular zones, each having a characteristic focal length, the invention encompasses an arrangement in which the zonal elements blend continuously one into another. The refractive surface of the lens can be mapped numerically so as to produce the desired characteristic. Thus, the light gathering capability of each zonal element - whether discrete or notional - will increase with an increase in associated target distance.

The preferred method for varying the light gathering capability of the zonal elements is, as described, to vary the effective area or optical aperture of the element. There are alternatives, however. In one example, zonal elements of equal area are coated with attenuating layers of differing transmissivity. This approach does have the drawback that the efficiency of light collection is reduced.

In the above described arrangement, the detector and the focusing lens are disposed coaxially with the outgoing light beam. Whilst this offers geometric simplicity, the dead zone around the axis of the focusing lens may be a disadvantage. An alternative arrangement will now be described in which the light detector and associated focusing lens are off the axis of the outgoing light beam.

Referring to Figure 4, a collimated light beam source 50 produces a light beam 52 which is directed towards a remote target (not shown). Light reflected from the target is collected by convergent optical means 54 and directed to a detector 56. A suitable arrangement may be provided for providing a calibration path directly from the light beam source 50 to the convergent optical means 54. The procedures by which a distance measurement is produced from the output of the detector 56 will be analogous to those discussed above.

The convergent optical means 54 has front and back refracting surfaces 58 and 60. Back surface 60 is a hyperbole of revolution, and images any collimated light travelling parallel to its axis onto the detector 56. The front surface 58 comprises surface zones each designed to collimate light arriving, off axis, from an associated target distance. As shown in Figure 5, the surface 58 is part of a rotationally symmetric surface having its axis of symmetry coaxial with the light beam 52. Each zone is associated with a particular target distance and light reflected from that target distance will be collimated, optimally, by the zone. The surface zones of the front refracting surface 58 are thus analogous with the described zones of the focusing lens in the first described embodiment. Again, as a practical matter, the zones may (and preferably will) blend continuously one into another and the contour of the front surface will be generated numerically. One example of a numerical solution is shown in Figure 6. In this graph, at plot A, the deviation of the front surface 58 from a plane surface is plotted against the zone diameter, this diameter being measured from the axis of the light beam 52.

Whilst, for any target distance, the light collimated by the front surface 58 - and thus focused by the back surface 60 - will have contributions from many parts of the front surface, there can be identified zonal elements having an associated target distance at which light is directed optimally at the detector. The required light gathering capability at that target distance can be readily calculated from the inverse square law. This provides a relative value for the effective area of that element enabling a shape for the front surface to be computed. To a first approximation this surface may be a cone centered on the axis of the outgoing light beam. Deviations from the conical surface provide the necessary correction. The graph which is Figure 6 shows - at plot B - the deviations from a conical surface for the same numerical solution.

It may be found that the design of a single optical element having a front, "correcting" surface rotationally symmetric about the beam axis and a second, "focusing" surface rotationally symmetric about the axis of the element, is difficult if problems of coma are to be avoided. It is therefore proposed, in a further embodiment of this invention, to provide the first and second refractive surfaces on different optical elements.

Turning to Figure 7, there is shown an arrangement in which the convergent optical means 54 is replaced by a correcting optical element 70 and a main focusing lens 72. The correcting element 70 may be formed of plastics material and can conveniently serve as the window of a measuring device. The front surface 74 of the correcting element is rotationally symmetric about the beam axis shown at 74 and serves, as described above, to collimate off axis light. The surface is approximately conical with an angle of typically a few milliradians and in this example between 2 and 8 milliradians. Blended zones of appropriate area in the surface 74 are associated with respective target distances. The focusing lens 72, without the design constraints imposed by the correction surface, can be designed to give low coma. Conveniently, the rear surface 76 of the correcting element 70 can be configured to correct spherical distortion of the main focusing element 72, in a Schmidt arrangement.

It is preferred that, as in the described embodiments, the zonal elements associated with the shortest target distances are disposed closest to the axis of the outgoing beam. This optimises the depth of field.



Temperature effects may become significant in certain high accuracy applications of the present invention. A decrease in temperature will, for example, shorten the focal length of an acrylic lens. In one form of the present invention, the zonal elements are so designed that as temperature changes, different zonal elements become associated with a particular target distance. The design is such that, within tolerances, the required compensation of intensity is maintained. If appropriate, a deliberate curl such as that shown at 78 in Figure 7 can be introduced into the correcting surface to compensate for temperature effects.

Whilst it is preferred to have the zonal elements in a single refracting surface, in appropriate circumstances, the elements may be divided. Moreover, the zonal elements can be formed in the convergent optical means otherwise than as part of a refracting surface. In one alternative, the zonal elements comprise respective regions of a reflective surface such as a parabolic mirror.

For ease of computation and manufacture, it is preferred that the zonal elements be rotationally symmetric about the axis of the outgoing light beam. The skilled man will appreciate, however, that this is not an essential requirement and that more general solutions exist which satisfy the requirement of varying the effective area of each zonal element in accordance with changes in the associated target range.

The convergent optical means will often focus light at the detector but in appropriate cases will merely direct light to the detector.

It should be understood that this invention has been described by way of examples only and a wide variety of further modifications can be made without departing from the scope of the invention as set out in the accompanying claims.

**CLAIMS:**

1. Optical apparatus comprising a light beam source; light detector means and convergent optical means for directing light returned from a target onto the detector means, characterised in that the convergent optical means comprises a plurality of zonal elements each having an associated target distance at which returned light is directed optimally onto the detector means, the light gathering capability of the respective elements varying as between the elements with an increase in associated target distance so as to compensate for the reduction in the intensity of reflected light as a function of said distance.

2. Apparatus according to Claim 1, wherein the light gathering capability of the respective zonal elements increases by virtue of an increase in the associated elemental area.

3. Apparatus according to Claim 1 or Claim 2, wherein the zonal elements comprise respective refractive surface zones.

4. Apparatus according to Claim 3, wherein the refractive surface zones are disposed concentrically of the light beam axis.

5. Apparatus according to Claim 3 or Claim 4, wherein the refractive surface zones are disposed in a common refractive surface.

6. Apparatus according to Claim 5, wherein the surface zones blend continuously one into another.

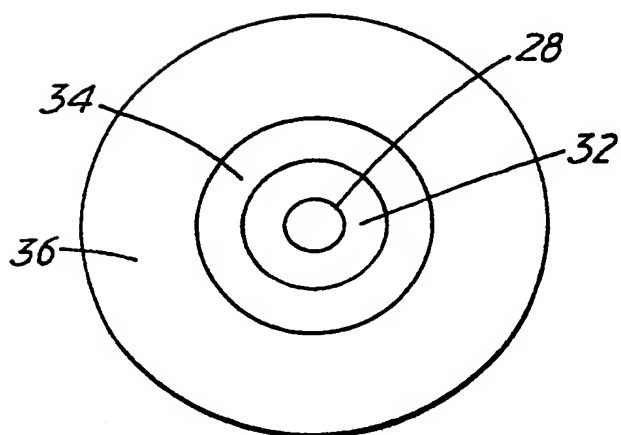
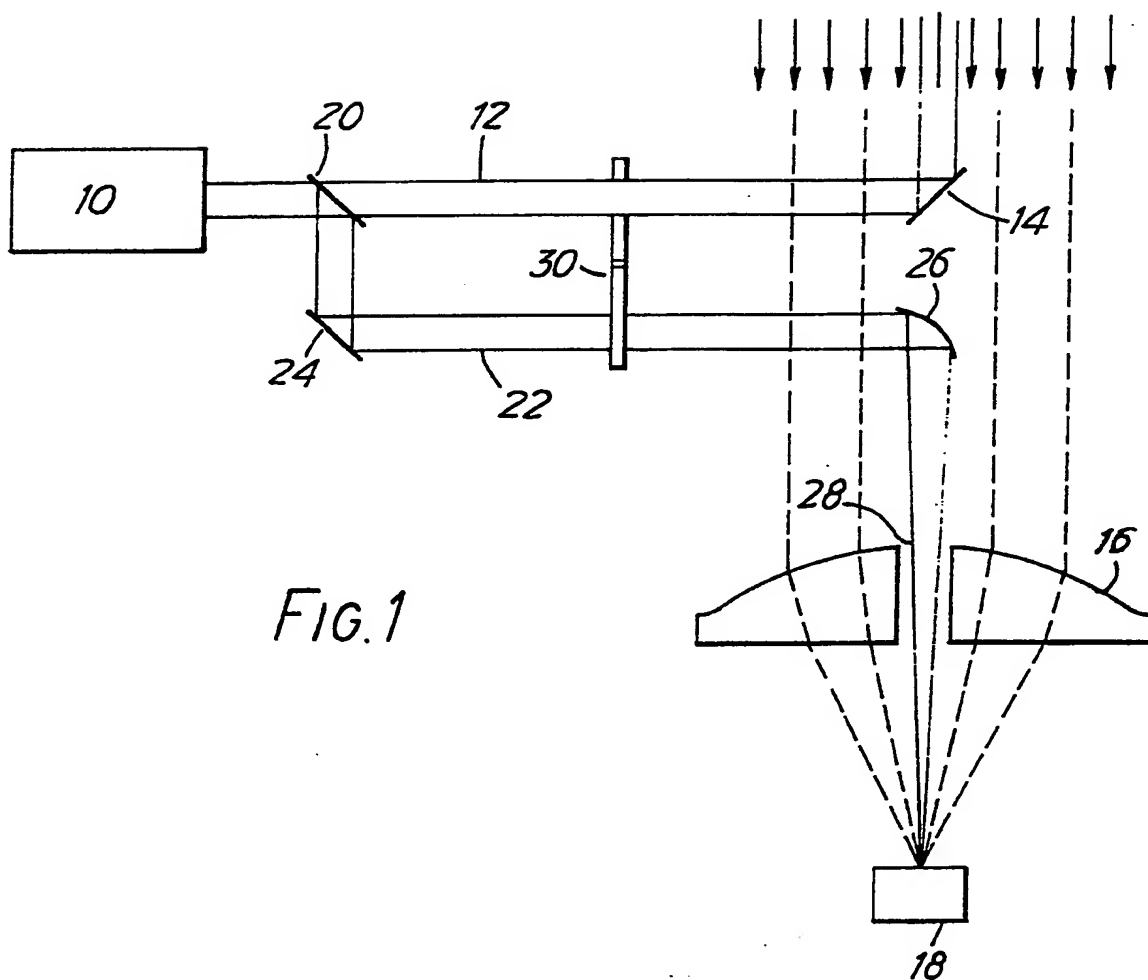
7. Apparatus according to any one of the preceding claims, wherein the zonal elements comprise respective zones of a first refractive surface, the convergent optical means including a second refractive surface, the first and second refractive surfaces being rotationally symmetric about respective, mutually spaced axis.

8. Apparatus according to Claim 7, wherein the first refractive surface is provided in a correcting optical element serving to collimate light returned from varying target distances and the second refractive surface is provided in a lens focusing collimated light onto the light detector means.

9. Apparatus according to Claim 8, wherein the correcting optical element further comprises a Schmidt correction surface.

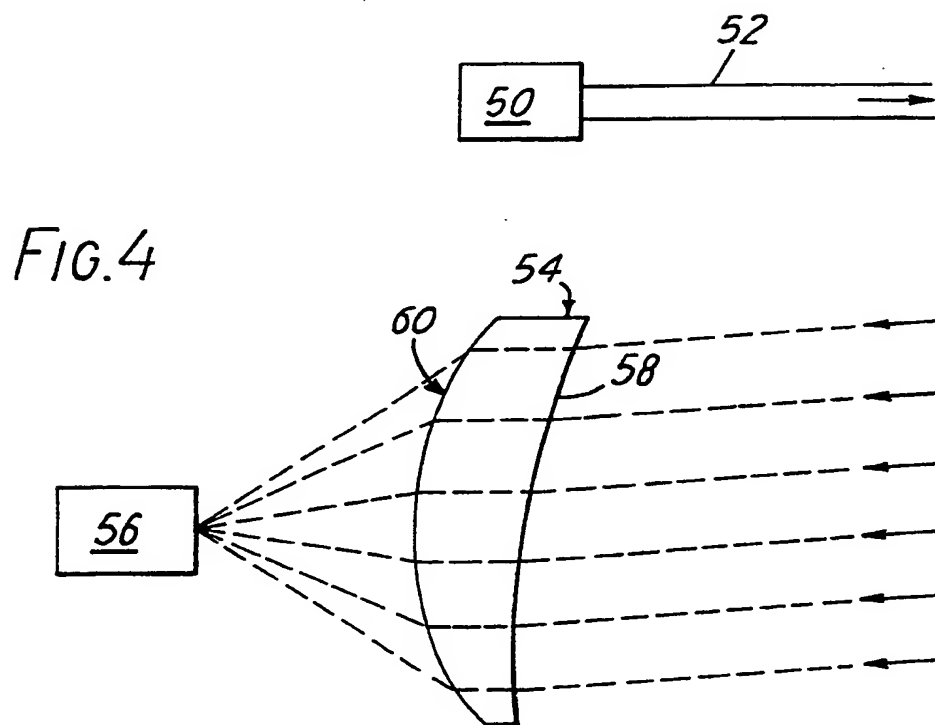
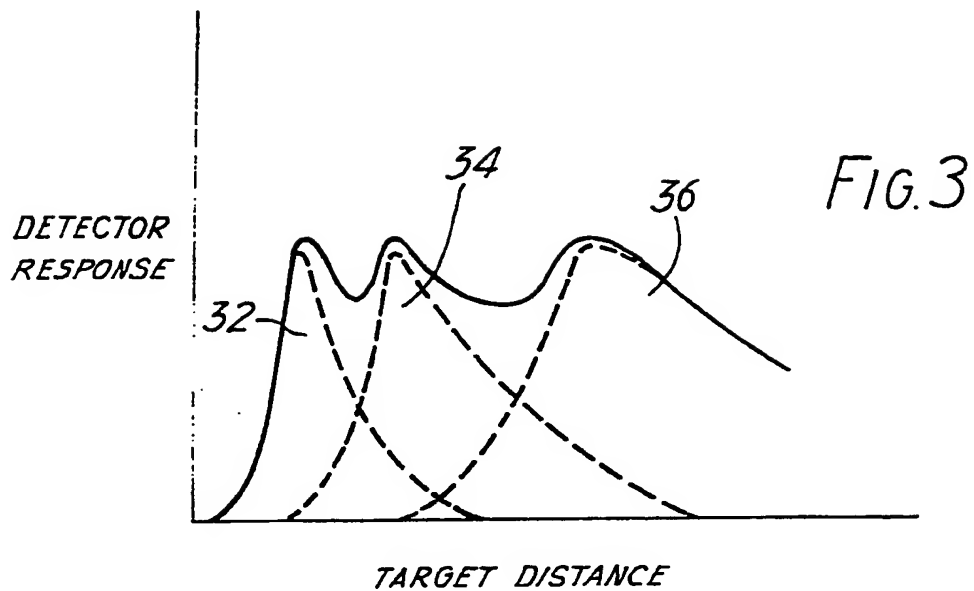
10. Apparatus according to any one of the preceding claims, wherein a specific target distance is associated with differing zonal elements as a function of the operating temperature of the apparatus.

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SUBSTITUTE SHEET

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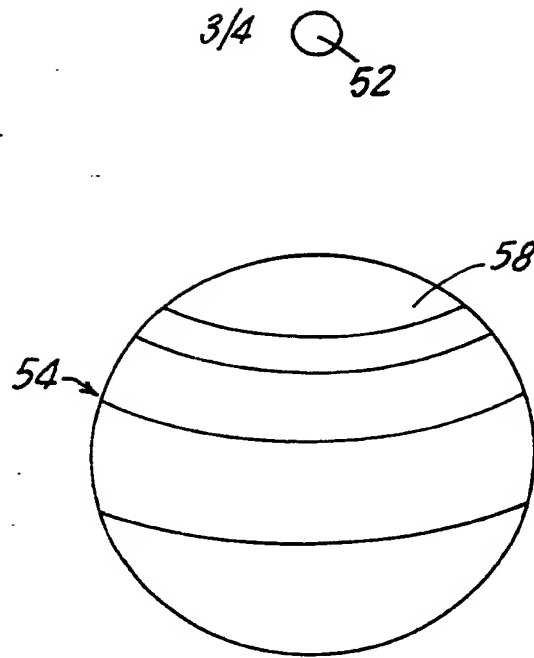


FIG. 5

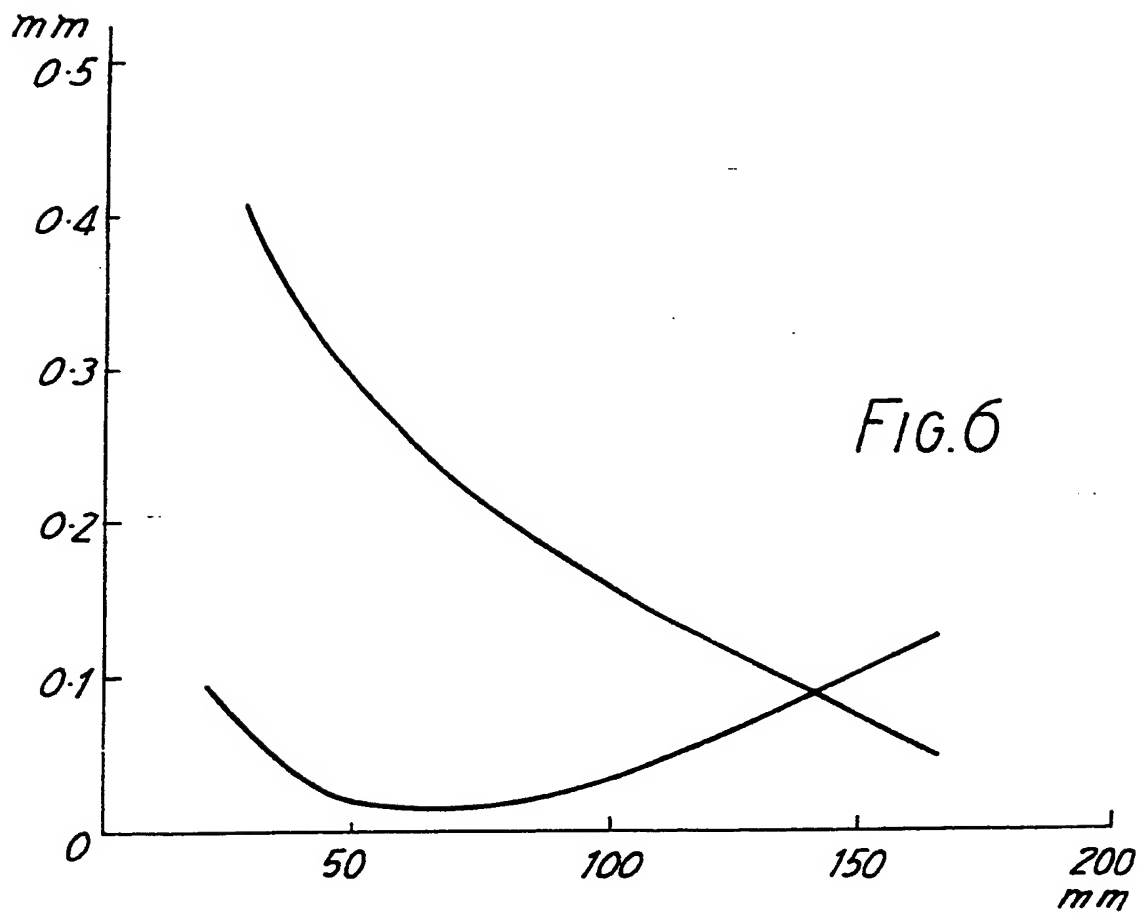


FIG. 6

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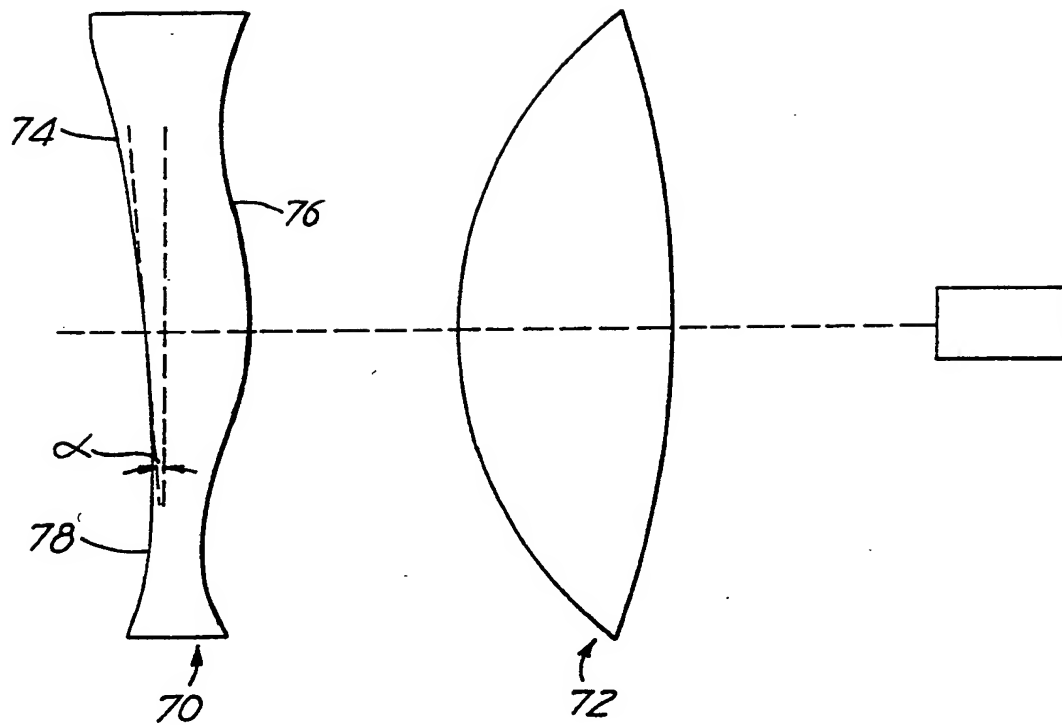


FIG. 7

## INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 91/01590

<b>I. CLASSIFICATION OF SUBJECT MATTER</b> (if several classification symbols apply, indicate all) <sup>6</sup>		
According to International Patent Classification (IPC) or to both National Classification and IPC Int.Cl. 5 G01S7/48; G01S17/32; G02B3/00		
<b>II. FIELDS SEARCHED</b>		
Minimum Documentation Searched <sup>7</sup>		
Classification System	Classification Symbols	
Int.Cl. 5	G01S ; G02B	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched <sup>8</sup>		
<b>III. DOCUMENTS CONSIDERED TO BE RELEVANT<sup>9</sup></b>		
Category <sup>10</sup>	Citation of Document, <sup>11</sup> with indication, where appropriate, of the relevant passages <sup>12</sup>	Relevant to Claim No. <sup>13</sup>
A	PATENT ABSTRACTS OF JAPAN vol. 11, no. 358 (P-639)21 November 1987 & JP,A,62 134 603 ( OMRON ) 17 June 1987 see abstract ---	1-5
A	PATENT ABSTRACTS OF JAPAN vol. 11, no. 112 (P-565)9 April 1987 & JP,A,61 260 178 ( MATSUSHITA ) 18 November 1986 see abstract ---	1-5
A	EP,A,0 384 353 (OMRON) 29 August 1990 see column 14, line 38 - column 15, line 36; figures 15,16,7,14 see abstract ---	1-5
A	DE,A,1 572 763 (NISSEN) 12 March 1970 see page 5, line 21 - page 6, line 15; figures 3,4 ---	1
-/-		
<p><sup>10</sup> Special categories of cited documents:</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"&amp;" document member of the same patent family</p>		
<b>IV. CERTIFICATION</b>		
Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report	
20 DECEMBER 1991	12. 02. 92	
International Searching Authority	Signature of Authorized Officer	
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# ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO.

GB 9101590  
SA 51339

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP-A- 0384353	29-08-90	JP-A- 2306513	19-12-90
DE-A- 1572763	12-03-70	None	
GB-A- 2122835	18-01-84	US-A- 4511248	16-04-85
		US-A- 4460259	17-07-84
		GB-A, B 2124051	08-02-84
		JP-A- 59022017	04-02-84

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
A	GB,A,2 122 835 (EASTMAN KODAK) 18 January 1984 see page 3, line 109 - page 4, line 18 see page 4, line 85 - line 98; figures 1,14  ---	1

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